

# UNIMILL for Prototype and Small-Batch Bevel Gear Manufacturing

Hermann J. Stadtfeld

## Introduction

The manufacturing of spiral bevel and hypoid gears can be conducted in several ways. The following methods are commonly known:

- A. Face hobbing with a circular face cutter that rotates while the work rotates in the opposite direction (continuous indexing).
- B. Face hobbing with tapered hob (peripheral cutter) that rotates while the work rotates as well (continuous indexing).
- C. Planing method with one or two tools that move linearly, while the work either is performing a roll rotation or a combination of roll rotations and an additional rotation for a spiral-shaped flank line (single indexing).
- D. Face milling with circular face cutter that rotates while the generating gear is not rotating, the work only performs a roll, but no indexing motion (single indexing).
- E. Universal 5-axis milling with pencil-shaped end mill or disk-shaped cutter (single slot manufacturing).

Methods A through D are well known and have been performed for more than 70 years. Method E became available with the possibility to enter complex free-form surfaces into the control of 5-axis universal milling machines. While the manufacturing time is between 10 and 100 times that of the processes A through D, the accuracy might generally be lower than that of the dedicated machines used to perform methods A through D. The advantage of 5-axis bevel gear machining is the flexibility; no special cutting tool is required and the bevel gear size is only limited by the size of the 5-axis machines available (Refs. 1–2).

Five-axis machining uses a spherical- or cylindrical-shaped mill to shape the flank surfaces. The data post-processing uses flank surface points and, in some cases, normal vectors to calculate the machining paths. The machining paths must be close enough to achieve enveloping paths that approximate the target surface with sufficient precision. The orientation of the enveloping paths (flats) is linked only to the machining strategy in order to minimize the machining time and the deviation from the target flank surface. It has to be considered in manufacturing of bevel gears with machining centers that a generated bevel gear tooth consists of up to 7 different areas:

1. Flank surface — first flank
2. Flank surface — second flank
3. Root fillet radius — below first flank
4. Root fillet radius — below second flank
5. Slot bottom — between both root fillet radii
6. Undercut section — below first flank and above root fillet
7. Undercut section — below second flank and above root fillet

The true profile and lead generation, according to the gearing law, only works within the flank surface and in the root fillet area, i.e., — from the flank transition down towards the root bottom, ending in the area of the 30° tangent point. Depending on the severity and character of the undercut, it is impossible to generate this area precisely with correct normal vectors. Also

the slot bottom — connecting the fillet region from the 30° tangent through the deepest bottom land to the opposite side root radius at the 30° tangent — cannot be generated using the common surface-generating algorithm for bevel and hypoid gears.

In regards to face-hobbed gears with extended toe or heel ends, it is also equally difficult or impossible to generate the extension of the flank surface, which in many cases does not consist of a true flank surface according to the gearing law. One typical example is slotted nose pieces that represent flank surface extension far behind the heel of the pinion to be clamped in front of the nose piece. However, those problem areas are formed with a face cutter head that represents one tooth of the generating gear. The generating gear (Fig. 1) will form them as: an undercut section, as root bottom area, or as enveloping forms cuts beyond the theoretical face width. If the undercut, root bottom area, etc. are formed by the generating gear, then it is assured that rolling without disturbances between pinion and gear can occur. Undercut, for example, is not an "evil" caused by the manufacturing process; rather, it is a geometrical necessity in order to assure correct rolling without interferences (Ref. 3).

But the solution for the problem areas is not a substitution of those sections with plane, cylindrical or parabolic surface elements, because of the risk of either weakening the teeth or causing rolling disturbances.

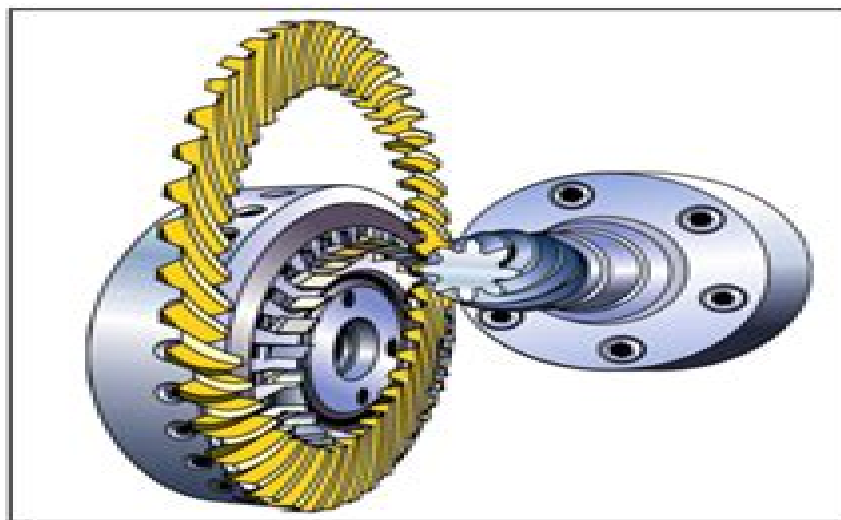


Figure 1 Face cutter representing one tooth of a generating gear.

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**American Society of Tool and  
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